ACOUSTIC EMISSION MONITORING SYSTEM

FOR

WELDING THICK-WALLED VESSELS

FINAL REPORT

by

TEKTREND INTERNATIONAL INC.
402 Isabey St.
St. Laurent
Montreal, Quebec
H4T 1V3

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ABSTRACT

This project was undertaken to apply advanced computer methods in combination with the SLAM (Signal Location and Acquisition Module) data acquisition hardware developed by Tektrend International Inc. under a previous contract for Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources, Canada to on-line weld monitoring. Using shop tests carried out in CANMET laboratories and in the welding shops of Versatile Vickers in Montreal, methods were developed to apply pattern recognition methods to acoustic emission source identification to reduce background and process noise problems and to provide a more powerful real time AE signal location and acquisition program that addresses and accommodates the industrial welding process environment. The ability to identify and classify process noises was demonstrated as was the use of acoustic emission as a routine inspection method.

PROJECT SCOPE

Several aspects of monitoring must be addressed to successfully apply acoustic emission monitoring to on-line weld inspection. These range from from noise problems and source (defect) identification to set-up considerations. Background noise, if not identified and accounted for, will provide false calls and reduce the usefullness and credibility of the method. The noise problem is closely related to that of flaw identification. Both require methods for recognizing the signals and classifying them. In this project, pattern recognition methods were used.

Another key to a useful and workable AE welding monitor is to overcome the lengthy and complicated setup and calibration procedures that usually associated with acoustic emission monitoring. In order to record precise source emission location the relative locations of each AE sensor as well as their analog characteristics have to be calibrated accurately. There are other external parameters that further complicate the process, such as the temperature and shape of the structure. A human interface was developed as were flexible source location programs to simplify set-up and calibration.

In this project, the following were addressed in order to develop a viable acoustic emission weld monitoring system:

* use of pattern recognition to differentiate among acoustic emission signals and noise
* to develop source location algorithms suited to monitoring welding in cylindrical vessels
* to reduce the high data rate generated during welding process, and
* to standardize the system set up procedure.

SOURCE LOCATION ALGORITHM

The signal location and acquisition software on the CANMET SIAM unit uses four acoustic emission channels to effect monitoring in a simple linear or square arrangement that can cover linear welds and non-linear (planar) weldments within the monitoring grid. This system worked well in a relatively clean and controlled laboratory condition where the experiment could be adapted to linear or planar geometries. However, special attention was required to address the common cylindrical setup that is often encountered in pressurized systems, especially in the circumferential welds. In addition, the original linear set up used only two sensors to calculate the linear location and therefore was subject to a large uncertainty when applied to structures such as a cylinder where the signal can reach the same sensor by more than one path and thus generate ghost locations.

A revised and improved location and acquisition software program was developed to overcome these problem. A new program called "ASAP" (Advanced Signal Acquisition Program) uses two new sensor arrangements "T-REC" and "T-CYL". The sensors are now arranged with three sensors aligned on one side of the weld and the 4th one lying on the opposite side in a "T" configuration. The "T-REC" set up will address both linear and planar weldment monitoring; the "T-CYL" set up is specially tailored for the circumferential welds found in cylindrical structures. The new source location algorithm always uses three sensors to effect the location calculation and the "ghost location" is eliminated. The "T-REC" set up is not restricted to a square and can be applied to any rectangular shape and is ideal for longitudinal weld monitoring.

DATA ACQUISITION ALGORITHM

The previous data acquisition software tended to take in too much data in the shop environment due to lack of selection criteria that ties the signal to the emission source. Data rates in the shop were much higher since conditions were less controllable. A new algorithm was added to the ASAP program to test the validity of the data based on the sensor arrangement. It eliminates those signals not originating from a emission source. As a result, the total number of signals being is substantially reduced to a more manageable number. A time stamp as well as the emission source location is automatically included in each signal record acquired thus providing a more detailed record of the signal. A special re-play mode is added to the ASAP program to allow the complete data acquisition session to be played back and the operator can check both the location and signal profile on the screen as he wishes.

SYSTEM SET UP PROCEDURE

Lengthly set-up and calibration procedures are intolerable in an industrial production facility. The system setup and calibration procedure should be short and easy to use. The ASAP program was revised and modified many times based the experience obtained in tests at CANMET and Versatile Vickers. This was achieved through an improved human interface for the operator. Instead of specifying the sensor configuration and reporting source location in terms of counter values of the machine, ASAP now accepts physical units such as "cm" as input and output units. On-line help screen is provided to help less experienced user to use the system. Pre-defined system set up can be loaded from a file and the user can save or produce hard copy of the system set-up all under simple key strokes. These greatly improve the time required to set up a system. For repeated similar system set-up, the time required has been reduced to less than 15 minutes which includes physical unpacking and connecting cables and sensor, and the calibration procedure using standard ultrasonic pulser.

AE SIGNAL ANALYSIS FOR INDUSTRIAL ENVIRONMENT

The difference between the laboratory testing and industrial production monitoring is quite obvious. We know what we are monitoring in the laboratory because all the flaws and defects were induced deliberately, while in the industrial production a great amount of effort is put into assuring the final product is of highest quality and free from defects. Monitoring was carried out under both of these conditions. A welding session was monitoired at CANMET of a steel alloy that required a very high temperature pre-heat process (~ 400 C). Other session were carried out with Versatile Vickers on nuclear grade welds in steel piping.

High Temperature Data Acquisition

Because of the unusually high temperature pre-heat treatment required for welding this particular type of steel alloy, these tests provided a unique opportunity to test the SIAM system and all the accessory equipment in such a harsh environment. High temperature sensors that could withstand up to 500 C were used. Because this alloy can only be welded within a given temperature range, once it was taken out of the oven, the system had to be set up within 30 minutes.

The weldment monitored was in the final 10 passes of the 3" thick weld. The calibration showed high consistency from the location of the pulser. During the welding, about 100 signals were recorded, all showed high consistency along the weld line and mainly associated with the welder's actions, such as slag removal, chipping, etc. From the playback of the data, it was observed that less than 10 percent of the data showed possible characteristics of AE signal associated with weld defects as we have learned from our previous studies. The rest is suspected to be related to the signal generated by pneumatic tools. No significant weld defects were found on this weldment by radiographic inspection. Because of lack of significant of known data samples, signal classification analysis was not performed. However, an extensive signal processing was done on each signal in different signal domains, time, power, autocorrelation and cepstral domains, select acoustic emission signals based on criteria from previous studies.

INDUSTRIAL ENVIRONMENT DATA ACQUISITION

Versatile Vickers is the prime contractor to fabricate the main steam pipe for use in Darlington nuclear generator station. Tektrend reached an agreement with the Vickers management to allow monitoring of some of the pipes being fabricated. The pipe was made from 1" thick steel plate. The dimension of the pipe is 3.8 meter long 76 cm in diameter. The steel plate is first rolled into the desired shape and hand welded together in the middle and then welded together by a semi-automatic welding machine from both inside and outside. Usually 8 to 9 passes were welded on each side, then every two sections of this pipe were welded together circumferentially.

Several tests werec carried out at Vickers. They consisted of a start up trip to familiarize with the environment and two mock set up sessions for both longitudinal and circumferential welds on already fabricated pipes. Rapid set-up was achieved to set up the system close to the welding station.

The subsequent trips were mainly for monitoring purposes. However, testing opportunities were confined to monitoring within the production procedures and schedules. Nevertheless, Tektrend did monitor over half a dozen of these pipes. Only longitudinal welds were. From radiographic post-weld inspection results on those pipes monitored, no significant defects were found. Thus, correlations to actual defect indications was not possible

Detailed logs were prepared on those pipe section that Tektrendhas monitored. The exact time of any signal generated from pneumatic tools or electrical noise was noted for later reference. In general there were 4 main classes of signal related to these type of origin:

* slag cracking

* slag removal (usually wire brushing)

* chipping

* transient noise (spark or arcing)

The first three types of signal is the most abundant and the last one only occured in two instances that we have observed and a small number of signals was available.

Besides these signals, there would be genuine acoustic emission signals associated with any weldment defects. Based on the result from the previous studies, a number of distinguishing features have been identified to differentiate between valid and invalid acoustic emission signals in different domains. Moreover, we have observed from this study the following characteristics associated from these signal sources:

a slag cracking signal usually has a very short rise time and fall time, its power spectrum is usually asymmetrical, the energy does not fall to zero at the extremes, and there are many obvious peaks in the spectrum,

Sparking or arcing signals usually have a much longer rise time and a short rise time and usually followed by a comparable sized second pulse. Their power spectrum does not fall to zero at the extremes and has very large side lobes. The main lobe is very large and concentrated at about 200 KHz which is far from the main 375 KHz resonance of the transducer.

Chipping with pneumatic tools produces signals with saturated short pulse trains. The greatest peak in the power spectra is usually around 250 KHz.

The data collect at Vickers were analysed carefully signal by signal. Signals with saturation were discarded from the analysis. Timing and location information were used to help pin point the types of signals from the log book of the monitoring process.

DATA ANALYSIS

Due to the lack of data from significant weld defects, a series of analyses based on artifacts was carried out. First, two-class problems were explored, then a three-class problem was analyzed. Insufficient data samples for the sparking or arcing signal class precluded inclusion of this class in the analysis. The analysis is performed using Tektrend's ICEPAK (Intelligent Classifier Engineering Package) software on the CALLAN computer. Data samples of each signal class were first split randomly into two sets, one for training and one for testing. Signals were first passed through a feature extraction program that extracts the standard 108 features in 5 different domains:

36 features in time domain
18 features in power spectrum
18 features in phase domain
18 features in cepstral domain
18 features in auto-correlation domain

Two-Class Problem Results

The recognition rates observed for classifying slag cracking versus chipping signals is given below:

CLASS	TRAINING	TESTING
AE	92.86%	100.00%
CHIP	92.86%	78.57%
	92.86%	89.29%

For this problem, a total of three features were used, namely, the number of peaks above 25% of maximum amplitude in the power spectrum, the partial power ratio in the 6th and 7th octant of the frequency range. The main differences between these two types of signal is in the energy domain.

The recognition rates observed for classifying slag cracking versus slag removal signals is given below:

CLASS	TRAINING	TESTING
AE	100.00%	85.71%
REMOVAL	100.00%	92.86%
	100.00%	89.29%

For this problem, a total of three features were also selected, they are percentage of the total area under the 2nd greatest peak in the time domain, fall time and full pulse width of the 2nd greatest peak in the time domain. Unlike the chipping, the slag removal shows a more definite difference in the time domain and the slag removal is likely to produce multiple peaks in the time domain while the genuine AE signal usually contains a large sharp rising peak and decays slowly.

Three-Class Problem

The three-class problem is made up from slag cracking, slag removal, and chipping signal classes.

CLASS	TRAINING	TESTING
AE	100.00%	85.71%
CHIP	100.00%	75.00%
REMOVAL	100.00%	85.71%
	100.00%	81.25%

Five features were used in this problem. They are percentage of total area under the 2nd greatest peak in the time domain, rise time of the 2nd greatest peak in the time domain, partial power ratio of the 2nd and 6th octant in the frequency range, and the 2nd greatest peak amplitude in the ceptral domain.

CONCULSIONS

As a result of this project, we have developed an advanced AE signal location and acquisition system based on the SIAM 4000 hardware. It has been tested in both high temperature and industrial production environments. The system software has addressed a most critical acceptance criteria for industrial usage --- ease of use with no interference with production. A 15 to 20 minute system set-up time is achieved for most applications. In applying advanced signal processing and pattern recognition techniques to analyze AE data gathered under industrial production conditions, ICEPAK has demonstrated the power to identify different kinds of artifacts associated with the welding process at high recognition rates. The features used to effect such results are mainly concentrated in time and power spectra with the exception of the more difficult three-class problem, a cepstral feature was used.